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An Evaluation Update

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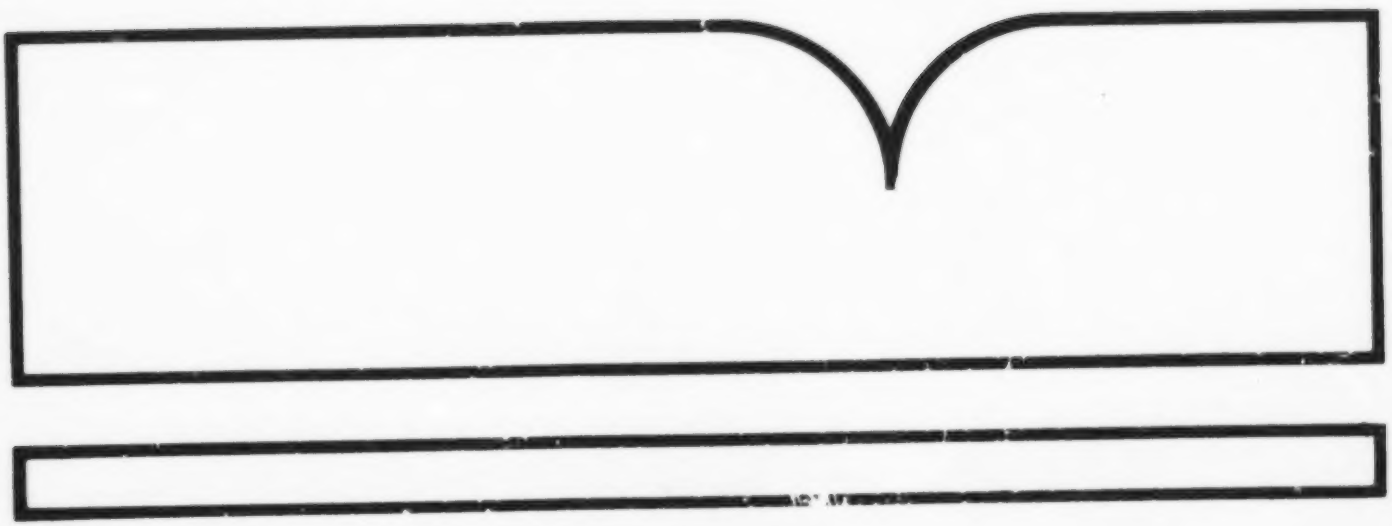

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16. ABSTRACT

Data acquired during the routine use of the Dohrmann DX-20 organic halide analyzer is presented as a basis for judging both the quality of TOX, POX and NPOX measurements, and as a basis for judging instrument dependability and ease of operation.

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JOURNAL ARTICLE

The analysis of organohalides in water—an evaluation update

Ronald C. Dressman and Alan A. Stevens

Data acquired during the routine use of an organic halide analyzer are presented. These data were used for judging the quality of measurements of total, purgeable, and nonpurgeable organic halides as well as for judging the instrument's dependability and ease of operation.

Organic halides are generally suspected of causing adverse health effects. For this reason, it is important to know of their presence in water that is intended for eventual human consumption. Only about 25 percent of the organic halides in chlorinated drinking water are detectable and measurable by chromatographic means, however, and the analysis of organic halides as a group parameter is valuable as a unique indicator of these potentially harmful substances.

The work described here was performed as a part of the evaluation of a method for the determination of organic halides in water by carbon adsorption. The original method of analysis was described by an instrument manufacturer at the invitation of the Drinking Water Research Division of the US Environmental Protection Agency (USEPA). The method was later refined during application testing and subsequent routine application to environmental samples in the USEPA Municipal Environmental Research Laboratory (MERL). This article is based on data acquired during those applications and is specific to both the method of analysis and the instrument* that was developed under contract to the USEPA by the manufacturer.[1] A description and evaluation of the method used with the instrument for determining carbon-adsorbable organic halides has previously been presented.[2,3] The paper by Dressman et al[2] should be consulted for a detailed description of the procedures and instrumentation. In the last quarter of 1980, MERL prepared a total organic halide (TOX) method that was published as interim method 450.1.[4]

Method

Description. Briefly described, method 450.1 consists of passing a sample of water (usually 40–100 mL) through a pair of minicolumns packed with 40 mg of granular activated carbon (GAC) previously milled and screened to 100–200 mesh. The minicolumns are mounted in series, and the sample passes through the columns with an inert gas under pressure. The organic halides are removed from the water by adsorption onto the activated carbon. After adsorption, the carbon is washed with a nitrate solution to remove interfering inorganic halide ions. The carbon is then transferred to a pyrolysis system in which the organic halides are combusted in a two-step process that converts first the volatile components and then the nonvolatile components to the hydrogen halide for subsequent online titration with silver ion and measurement by microcoulometry. Combustion takes place in a CO_2-rich atmosphere in the first stage to enhance the conversion of organic bromides to titratable species. In the second stage, the remaining components and the carbon itself are completely combusted in an O_2-rich atmosphere. All halide species are measured as chloride ions and are interpreted to represent a measure of carbon-adsorbable organic halides (CAOX), which are usually considered to be a reasonable estimate of TOX in drinking water samples. A second measurement capability exists with the available instrumentation, namely, that for purgeable organic halides (POX). This operationally defined measurement consists of purging a 10-mL aliquot of the sample with CO_2 at a temperature of approximately 45°C directly into the pyrolysis furnace for online measurement of the combusted organic halides by microcoulometry.

Scope of evaluation. Data were assembled to evaluate this method of TOX analysis with regard to adsorption efficiency for both samples and standards. Particular emphasis was given to the function of columns in series, the repeatability of sample results, and the precision of standard measurements. Data were also assembled to evaluate the POX measurement relative to the measurement of trihalomethanes (THMs) by the purge-and-trap method. The differentiation of TOX, POX, and nonpurgeable organic halides (NPOX) was also considered, as were the instrument's dependability and the problems that were associated with sample storage.

Repeatability of results

The repeatability of results is well demonstrated by the data presented in Table 1, which are typical of those generated in a routine operation.

As would be expected, repeatability was poorest when the instrument was operated near the lower limit of detection. The cutoff at 25 μg/L was arbitrary, of course, and most concentrations in this range were at or below the theoretical detection limit of 10 μg/L. Throughout the range of concentrations from 26 to 4000 μg/L, repeatability was excellent and exhibited little variability, as can be seen by comparing segments of the range to the entire range, 26–4000 μg/L.

Information about the type of repeatability presented here has been used to set criteria for accepting or rejecting data. Duplicates are routinely run on each sample because of the lack of ruggedness of the method, i.e., the vulnerability of the method to random positive bias, generally attributed to the ease with which the activated carbon can become contaminated during the preparation of the minicolumns. To prepare the data in Table 1, it was necessary to reject any pair of duplicates that were not within 50 percent of one another. Analysis of those samples was repeated as a matter of routine. Seven such incidents occurred in the block of samples used to obtain the data in Table 1. Thus, of the 137 samples originally run as duplicates, 5 percent were repeated for failing the 50 percent criterion.

By eliminating those samples from the database, a tighter precision was imposed on the method. The data in Table 1 are representative of the type of repeatability that can be expected from a technician after a minimum of four weeks bench experience, i.e., training. Duplicate sample results for TOX in the range of 0–25 μg Cl^-/L were accepted if their results did not differ by more than 34 percent (mean difference of 20 percent plus one standard deviation of 14 percent), whereas duplicate sample results in the range of 26–4000 μg Cl^-/L were accepted if their results did not differ by more than 16 percent (mean difference of 8 percent plus one standard deviation of 8 percent). Samples whose

*DX-20, Dohrmann/Envirotech, Santa Clara, Calif.

J. AWWA, 75(8):431-434, 1983

TABLE 1
*Repeatability of results**

Range of TOX Concentration μg Cl^-/L	Number of Samples	Mean Difference in Duplicates percent	Standard Deviation of Differences in Duplicates ±percent
0–25	27	20.50	14.02
26–200	45	8.93	8.31
201–500	14	8.93	8.53
501–1000	22	7.36	5.79
1001–4000	25	9.08	7.87
26–4000	106	8.64	7.70

*Analyses performed on finished water samples

TABLE 2
*Adsorption efficiency of the first column**

Number of Samples	Load Applied to First Column† μg Cl^-/L	Average of Total Trapped on Second Column percent	Standard Deviation of Average ±percent
56	0–2	6.30	11.18
52	>2<5	7.07	4.69
49	5–10	6.38	5.42
46	>10<20	6.25	4.50
39	20–45	9.45	4.52
29	>45<60	9.36	4.57
13	60–90	9.98	5.69

*From analyses of finished water samples
†Represents the full amount of TOX contained in the volume of sample taken for analysis and adsorbed onto carbon

TABLE 3
Comparison of TTHM analyses—TTHMs by purge and trap versus POX (TTHMs) by the instrument procedure

Instrument Method*			Purge-and-Trap Method			Average Difference† percent
Number of Analyses	Average POX μg Cl^-/L	Standard Deviation	Number of Analyses	Average TTHMs μg Cl^-/L	Standard Deviation	
41	110	±7	6	138	±6	20

*Data obtained by using a vitrified combustion-tube insert in the inlet
†Percent by which POX is less than TTHM measurement

TABLE 4
Comparison of POX analyses—TTHM (POX) by purge and trap versus POX by the instrument procedure

True Value*	TTHM μg Cl^-/L	POX μg Cl^-/L	Difference† percent	True Value*	TTHM μg Cl^-/L	POX μg Cl^-/L	Difference† percent
8.5	4	9	-56	60.5	56	65	-14
8.5	11	2	+82	61	55	67	-18
7	7	7	0	62	58	66	-13
12.5	21	4	+81	63	67	59	+12
15.5	10	21	-53	65	71	59	+17
17	12	22	-46	67.5	60	75	-20
20	27	13	+52	72.5	71	74	- 4
20	6	34	-82	77	70	84	-17
20.5	16	25	-46	78	75	81	- 8
22	18	26	-31	88.5	88	99	-12
24	15	33	-55	97.5	98	97	+ 1
30	35	25	+29	109.5	110	109	+ 1
32	25	39	-36	114	114	114	0
33	28	38	-27	115.5	108	123	-12
35	38	32	+16	120.5	121	120	+ 1
36	27	45	-40	133	131	135	- 3
38	42	34	+19	135	136	134	+ 2
38.5	25	39	-36	138.5	139	138	+ 1
39	31	47	-35	145	144	146	- 2
41	42	40	+ 5	162.5	169	156	+ 8
45	49	41	+19	170	169	171	- 1
48	46	50	- 8	189	194	184	+ 5
51	49	53	- 8				

*True value was arbitrarily calculated as the average of both (instrument and purge and trap) determinations.
†A negative difference refers to the percentage of POX by which TTHM is less than POX. A positive difference refers to the percentage of TTHM by which POX is less than TTHM.

TABLE 5
*Comparison of the sum of NPOX + POX versus TOX**

NPOX + POX = TOX μg Cl^-/L	TOX† μg Cl^-/L
212 + 107 = 319	334
201 + 93 = 294	282
205 + 104 = 309	307
233 + 119 = 352	340
221 + 101 = 322	300

*All results are the average of at least triplicate analyses of finished water.
†Direct measurement

duplicate results differed by more than the stated percentages were analyzed again, and the two results of the three replicates that were within the stated percentages were accepted. Anytime no more sample was available for repeat analysis, the two results whose difference was closest to the stated percentages were accepted and averaged.

For the concentration ranges of 0–25 μg/L and 26–4000 μg/L (Table 1), 13 percent of the samples were reanalyzed based on the preceding criteria. Depending on the need (the use of the data) for such stringency in verifying results, the criteria for accepting duplicate results may be relaxed. The preceding set of data is presented as a demonstration of the capability of the method and has remained essentially the same in the hands of six different analysts. Original specifications for the TOX analyzer system[1] called for a ±2 μg/L or ±2 percent precision, whichever is greater, and this was achieved for about 25 percent of the samples.

Adsorption efficiency

The purpose of the second minicolumn is to trap breakthrough off the first column, should it occur. Original specifications[1] called for 95 percent ± 2 percent of a 2,4,6-trichlorophenol (2,4,6-TCP) concentration of 100 μg Cl^-/L to be recovered on the first column and the remaining 5 percent ± 2 percent to be recovered on the second column.

In the actual practice of recovering 2,4,6-TCP from water as a check on adsorption efficiency for each new batch of carbon (13 tests using a 2,4,6-TCP concentration of 40 μg Cl^-/L), an average of 93 percent ± 5 percent of the chlorine was accounted for and was generally recovered on the first column. Activated carbon that does not meet this standard (93 percent ± 5 percent recovery of 2,4,6-TCP) should not be used.

Even disregarding those compounds that may be poorly adsorbed on GAC (e.g., chloroethanol) and those that may be desorbed by the nitrate wash (e.g., chloroacetic acid) and, therefore, not measured on either column, it is not easy to interpret the efficiency of adsorption for sample analysis. Ideally, the TOX recovered by the second column will equal the TOX in the nitrate-wash blank, thereby indicating no breakthrough. The results for the second column, however, are vulnerable to the random positive bias that can occur from contamination of the columns during preparation. This random bias and the degree of precision associated with the nitrate-wash blank (generally a 0.5–1 μg readout) can easily influence any evaluation of the second-column result calculated as a percentage of the first-column result, especially if the amount of TOX loaded on the columns is less than 10 μg Cl^-. For example, at loads of 10 μg Cl^- or less, second-column results

indicate a 6 percent to 7 percent breakthrough when none should be expected to occur. On the other hand, as the load increases from 20 to 90 μg Cl^-, the average breakthrough is approximately 10 percent (Table 2). Evidence that these breakthrough values may actually occur at the higher levels is occasionally demonstrated when, for a given pair of duplicates, the results for both columns agree within 5 percent of one another whereas individual results for the first column may differ by as much as 25 percent.

Using data for the first column (Table 2), one can deduce that the load on the second column would have to reach 20 μg Cl^- before as much as 10 percent of that load would be lost from the second column. For only five samples did the second-column load exceed 10 μg Cl^-, with the highest being 19 μg Cl^-, and then only for samples whose initial load was 40 μg Cl^- or more. Because the percentage calculated to reach the second column is believed to be biased high for the lower loads, the loss from the second column is probably considerably less than 10 percent in the vast majority of cases. Nevertheless, in addition to minimizing loss, limiting the load on the first column to 50 μg Cl^- is recommended for two other reasons, namely, to avoid swamping the titration cell and to avoid unnecessary fouling of the system.

Analytical instrument precision and accuracy

The precision and accuracy of the analytical instrument system alone (pyrolysis followed by online microcoulometric titration) has been established by routinely analyzing a standard of 2,4,6-TCP several times each day during routine analysis. Five micrograms of 2,4,6-TCP were deposited on an activated carbon column previously washed with nitrate solution. After the activated carbon was pyrolyzed in the usual way and the average nitrate-wash blank for the day was subtracted, the percent recovery was calculated. A total of 51 such tests, which were consecutively recorded according to the established routine, resulted in an average recovery of 97 percent ± 6 percent. This criterion was used to judge the performance of the analytical system against similar tests conducted each day. As previously discussed, precision was not as good as that described in original performance specifications.[1]

POX in THM-dosed samples

A sample of organic-free, deionized water* was dosed with four THMs—chloroform, dichlorobromoform, dibromochloroform, and bromoform. The test batch contained 77 percent chloroform (106 μg Cl^-/L) and approximately equal amounts (10 μg Cl^-/L) of the other THMs. This sample was analyzed for total trihalomethanes (TTHMs) by means of purge and trap† and for POX by means of the instrument procedure. The results of these analyses were compared, and the data appear in Table 3.

These results did not agree with previously published results,[1,3] which included a 94 percent recovery of chloroform and a 100 percent recovery of bromoform from standard solutions. A similar discrepancy in results has routinely been observed when POX results were compared with TTHM results for finished water samples, in spite of the fact that one would normally expect both POX and THMs to be purged from a sample during POX analysis and that the sum of these would exceed the TTHM concentration when both are measured as the chloride ion. Attempts to pinpoint the cause of the low POX results were made by purging standard solutions of chloroform. The use of CO_2 instead of O_2 as the combustion gas, the method of purging directly into the furnace, and the high flow rate (150 mL/min) of the purge gas were eliminated as contributing factors. The condition of the combustion-tube insert was found to affect results, however, and when a highly vitrified tube was replaced with a new tube, chloroform was completely recovered from standard solutions. In spite of this correction to the system, POX measurements on finished drinking water samples remained 10 percent to 20 percent lower than corresponding TTHM calculations. The reason for this bias has not been uncovered but is apparently related to the sample matrix.

POX in chlorine-disinfected, humic-acid-dosed samples

In order to further investigate the problem of low POX values, results for THM analysis by purge and trap were compared with results for POX analysis by the instrument procedure. The samples used for these analyses were from an independent study[5] to determine the rate of formation of organohalides over a 144-hour interval. The samples consisted of organic-free, deionized water containing 5 mg humic acid/L in the presence of 20 mg free available chlorine/L. After analysis, results for the individual THMs were summed and converted to units of micrograms per litre as Cl^- in order to compare them with POX results. The data appear in Table 4.

The actual concentration of POX in each sample was assigned a "true" value, which was arbitrarily calculated as the average of the results obtained with each method (instrument and purge and trap). This calculation was made so that the results could be listed in an apparent order of increasing concentration. With the results listed in this order, several observations can be made to provide evidence that the two analyses can produce essentially equal quantitative results when the matrix is organic-free, deionized water. First, a random distribution of occasions exists in which one or the other of the analyses produces the higher result. Second, the percent difference between results is predictably higher at the lower concentrations represented by the true values from 6.5 to 39 μg/L, reflecting the poorer precision of both methods at the lower levels. Third, as concentrations increase from 40 to 88.5 μg/L, the percent difference lessens dramatically, until from 97.5 to 189 μg/L essentially no difference exists between results.

The sum of NPOX + POX versus TOX

Several experiments were conducted that simultaneously evaluated the carbon adsorption method of trapping organohalides (generally referred to as the TOX procedure) and the method of purging with online pyrolysis and detection afforded by the instrument (generally referred to as the POX procedure). Tap water was sampled five times over a period of five weeks. After sodium sulfite was added to reduce residual chlorine, each sample was split into aliquots for the following analyses: TOX, POX, NPOX. The samples for NPOX analysis were prepared by purging volatiles from them, as verified by POX analysis, and were then analyzed for TOX.

The results of these analyses are presented in Table 5. The samples were not meant to be replicates of one another, and the results probably reflect some fluctuation in concentrations of organic halides in the distribution system. The agreement between the sum of NPOX + POX and TOX measured directly is excellent. One conclusion that can be drawn from these data is that about the same proportion of THMs is unaccounted for by the TOX and POX measurements (noted as a matrix effect for finished water); otherwise there would be a bias in the direct TOX measurement. The results verify the validity of obtaining NPOX measurements by subtracting POX from TOX. This failure of TOX measurement to account completely for THMs, however, means that NPOX determined by subtracting converted gas chromatographic results is biased low by 10 to 20 percent.

Instrument dependability

The adsorption module is essentially trouble-free, except for occasional problems with broken wires on connections of the liquid-level sensors. These problems are easily corrected and can be minimized by careful handling of the sensors. One other minor problem to watch for is deteriorated O-rings that cause leaks.

The microcoulometric titration system must be carefully tended in order to keep the titration cell, the pyrolysis system, and the inlet system clean. One can easily

*Millipore Super-Q System, Millipore Corp., Bedford, Mass.
†Method 501.1, USEPA, Cincinnati, Ohio

develop a feel for the frequency at which the cell must be flushed and at which the cell (including the electrodes) must be thoroughly cleaned as instructed by the manufacturer. Frequency varies with sample load and the concentration of organic halides being combusted. The operator should also be aware of the possibility of corrosion by acetic acid electrolyte of all cable and electrode jacks.

The frequency at which the pyrolysis system must be cleaned (or the inlet and exit tubes replaced) depends largely on the concentration of organic compounds adsorbed onto the activated carbon. A strip-chart recorder is a useful aid in determining when a system is becoming fouled and in need of cleaning. Misshapen or fragmented peaks and low results on control standards can signal either that the system should be cleaned, the inlet and exit quartz-wool plugs should be replaced, or the inlet tube should be replaced because it has become too vitrified. After steady, prolonged use, the entire pyrolysis tube may have to be replaced because of vitrification.

Another problem that must be constantly guarded against is the presence of air bubbles anywhere in the titration cell's reference arm, particularly in the capillary connection to the silver acetate repository. Erratic measurements and an inability to stabilize the baseline are the results of the interruption in continuity with the rest of the electrolyte in the cell. Electronic malfunctions occasionally occur, but most are easily identified by running the manufacturer's internal instrument checks and are correctable by replacing the appropriate P.C. board.

With proper attention to these details, the instrument operates with a minimum of difficulty, and an experienced analyst can analyze eight samples in duplicate along with recommended quality control samples in an eight-hour day.

Storage of samples

Every laboratory should be aware of the problems associated with storing finished drinking water samples. Loss of TOX is one problem and was first reported by Sorrell,[6] who determined that losses could be minimized by storing samples at 5°C. These losses, which have also been detected by MERL, range from 10 to 20 percent over two weeks and are speculated[6] to be the result of metastable compounds breaking down in the absence of a free chlorine residual. Because these compounds are produced by the chlorination process, they would not be a factor in the storage of raw surface and groundwaters.

Determining the optimum holding time for finished drinking water samples is not easy. Allowing a minimum of two weeks for a sample to stabilize at ambient temperature before it is analyzed may be the best way to control the quality of TOX data for several reasons. First, the sample treatment would be more consistent with a two-week holding time than with a shorter holding time so that if a date of analysis was missed, the organic halide concentration would not likely be in the process of changing. Second, metastable compounds may (because they are metastable) be of little significance as pollutants. Last, metastable compounds may vary from source to source and with time of sampling, thus making a two-week holding time critical in terms of accurately measuring significant organic halide materials for comparative studies.

On the other hand, knowing the full amount of TOX in the sample may be more important even though some of the compounds may be metastable. If that is the case, then a die-off curve should be calculated for each source of samples, and the correction required should be noted when the data are reported.

More must be learned about the reasons for the loss of TOX and how to control that loss. In the meantime, decisions about storage time should take potential losses into consideration and should be made with regard to how good data must be to satisfy the ultimate use of that data.

In addition, one must also guard against the possiblity of TOX increasing during storage of samples, as would be the case if insufficient or degraded reducing agent was used to remove residual chlorine. For example, 0.1M sodium sulfite has been found to be unstable and is no longer recommended as the reducing agent. Instead, a 5-mg/L dosage of sodium sulfite crystals should be used.

Summary

The repeatability of results obtained during routine analysis was used to set criteria for accepting or rejecting data. Duplicates of samples containing a TOX concentration of 25 μg Cl^-/L or less were accepted if within 34 percent of one another. Duplicates of samples containing more than 25 μg Cl^-/L were accepted if within 16 percent of one another. Adsorption-efficiency tests on each batch of activated carbon were judged against the criterion that 93 percent ± 5 percent of the 2,4,6-TCP (40 μg Cl^-/L) must be recovered. An evaluation of the percent of breakthrough onto the second column at various loads ranging from 1 to 90 μg showed that recovery of organohalides is accomplished to within at least 95 percent of the load applied. A load limit of 50 μg was recommended for optimum performance. The criterion for judging acceptable performance of the analytical instrument system was 97 percent ± 6 percent recovery of 5 μg 2,4,6-TCP (as Cl^-) pyrolyzed from 40 mg of activated carbon.

The method for determining POX was compared with the purge-and-trap method for determining TTHM. The results indicated that POX equals TTHM for organic-free, deionized water samples, but a matrix effect lowers the POX result by 10 to 20 percent for finished water samples. Tests on standard solutions of chloroform showed that a vitrified combustion-tube insert reduced recovery of chloroform by approximately 20 percent. Experiments that measured TOX, NPOX, and POX directly and independently on the same sample verified that NPOX plus POX equals TOX and, therefore, NPOX can be determined by difference after TOX and POX are analyzed. Converting TTHM to units of POX and subtracting from TOX, however, produces a result for NPOX that is biased low (10 percent to 20 percent) because the TOX procedure does not completely account for THMs.

The instrument was dependable. A strip-chart recorder proved useful in indicating when the cell and pyrolysis system must be rejuvenated. The method was learned and applied to routine analysis by six different technicians with as little as four weeks training. An experienced analyst can analyze eight samples in duplicate along with recommended quality control samples in an eight-hour day with a properly operating system.

A decrease or increase in TOX concentration of the sample during storage can adversely affect the quality of measurements. A two-week holding time was suggested to avoid problems with a decrease in TOX. Sodium sulfite crystals rather than highly unstable sodium sulfite in solution should be used for reducing residual chlorine.

References

1. Joyce, R.J. Proposal to Supply TOX Analyzer Systems. Dohrmann Instrument Co., Santa Clara, Calif. (Jan. 1979).
2. Dressman, R.C. et al. The Analysis of Organohalides (OX) in Water as a Group Parameter. Proc. AWWA WQTC, Philadelphia (Dec. 1979).
3. Takahashi, Y. et al. Measurement of Total Organic Halides (TOX) and Purgeable Organic Halides (POX) in Water Using Carbon Adsorption and Microcoulometric Detection. Proc. ACS Sym. on Chemistry and Chemical Analysis of Water and Waste Water Intended for Reuse. Houston (Mar. 1980).
4. Total Organic Halide, Method 450.1—Interim. Prepared by R.C. Dressman for the Physical and Chemical Methods Branch, Environmental Monitoring and Support Laboratory. USEPA, Cincinnati, Ohio (1980).
5. Dressman, R.C. et al. Study of Organic By-Products of Disinfection. Unpublished data.
6. Sorrell, K. Stability of Total Organic Halide in Environmental Water Samples. Submitted for publication.

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